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"Sensor-Filter" – Intelligent micro filter system in foil technology

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Abstract

A novel micro filter system (sensor filter) enables standalone detection of its own loading status as well as monitoring the filtrate for the first time. This sensor filter consists of two micro-perforated sensor-foils containing interdigital capacitors (IDC) and a filter membrane placed in between. The capacitive detection of the filtrate (cells or particles) is possible via the alteration of the permittivity of the fluid upstream the filter at the "upper" IDC. The "lower" IDC downstream the filter serves to compensate temperature and/or conductivity variations of the fluid itself. The calculation of the sensor filter behavior using an elementary IDC model and an estimation of the filtrates permittivity applying different continuum models explains the sensor's response qualitatively. This theoretical model was confirmed by measurements with particles and yeast cells.

1. Motivation

Common ultra micro filters deployed in technical facilities currently do not allow an easy detection of the filter membrane's loading status. Almost completely clogged filters can be recognized due to pressure drop in the system. However online monitoring of the actual loading status as well as the electroanalysis of the filtrate can be useful in the development of process, hygienic status and cell culture control. Integrating the sensors filter into a compact and disposable module together with an electronic unit may enable a fast, simple and cost effective measurement tool.

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2. Concept and technological realization

The sensor filter consists of two circular sensor foils with interdigital capacitors (IDC). The size of the IDC was chosen to be compatible to 13 mm filter membranes. The electrodes show a 40 µm line / space distance to realize exact laser perforation for a high flow rate. The IDC were manufactured using an Au thin film process on a flexible polyimide substrate including a passivation with 1 µm parylene. The contact strip of the IDC's is compatible to commercial 1 mm pitch ZIF sockets (Fig. 1). After manufacturing the electrodes were perforated using a laser (hole size 120 * 25 μm^2, Fig. 2). Two IDCs enclose a filter membrane in form of a sandwich to form the sensor filter stack (Fig. 3). For the investigation a nuclear track filter (Pall 0.4 µm pore size) was chosen, which offers a planar surface.

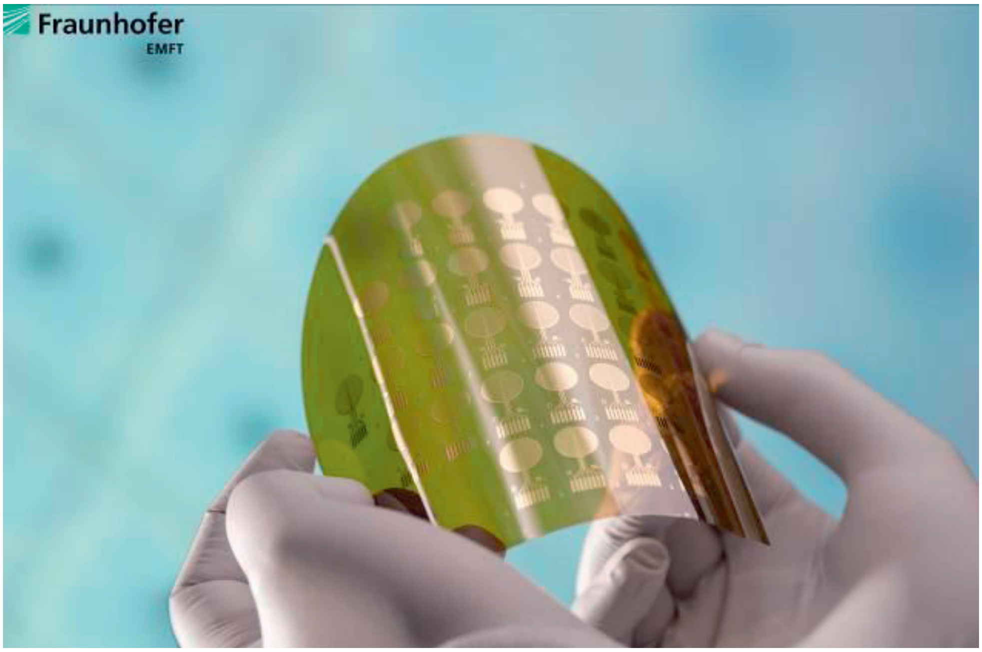

Fig. 1. Foil with perforated IDC's

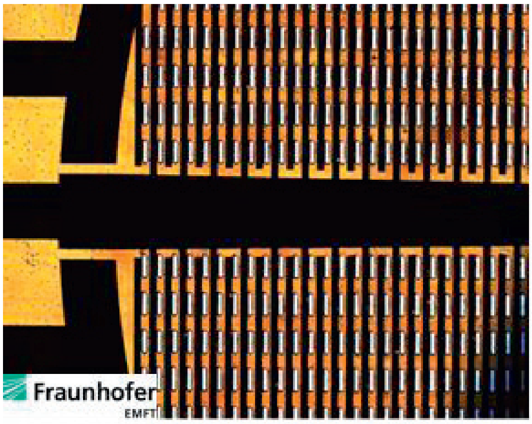

Fig. 2. Foil with electrodes and laser-cut holes (ca. 120 * 25 µm)

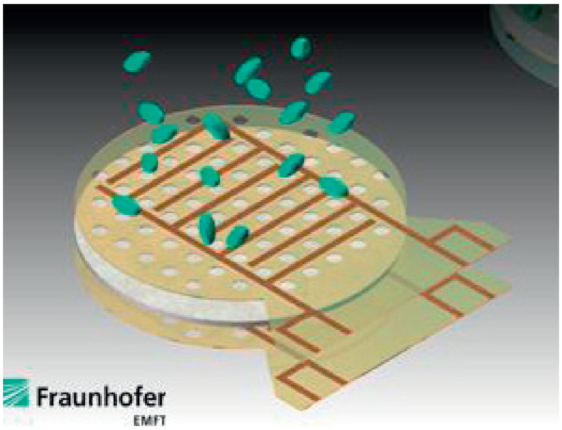

Fig. 3. Scheme of the sensor filter stack

3. Experimental setup

For measurements a special fluid and sensor housing has been developed (Fig. 4). The sensor filter was stuck between two chambers and borne by a polymer grid to avoid deformation caused by the flow. Each fluid chamber ("upper" and "lower") has two fluid connections to eliminate bubbles and to allow cross flow for cleaning the filter. The fluid setup consists of flexible silicon tubes and a peristaltic pump. The total setup including all fluids was kept at constant temperature for evaluation measurement controlled using a PT1000 sensor. The capacitance was measured with a HP 4192 impedance analyzer, the temperature by a Keithley 2001 in combination with a PT1000 resistor and the flow rate with a laboratory balance.

Fig. 4. Open measurement chamber for the sensor filter (bottom part with silicon seal – red)

4. Results

The sensor filter was tested using a solution of 10 µm Polystyrol beads and yeast *(Saccharomyces cerevisiae)* in defined laboratory water which was obtained after addition of NaCl (110 mg / l, laboratory grade) to purified water (Rotipuran). The conductivity of the laboratory water was similar to that of tap water. All experiments have been performed at room temperature because no significant temperature alterations (< 0.5 °C) during a measurement run (45 min) were observed.

A measurement experiment starts with a run-in period by spoiling the system with water for generating a stable basic signal. After 10 minutes the beads or cells were added to the water storage (pipette, magnet stirrer) and after additional 20 minutes the measurement was stopped. All resulting measurement curves were aligned to a zero point at the moment of addition of particles in order to compensate e.g. the influence of production variations of the IDC's, water mixture or actual room temperature.

Results obtained follow an exponential growth curve (beads, Fig. 5) and an exponential decay curve (cells, Fig 6). The contradictory behaviour of the sensor response to cells and beads can be explained qualitatively using an elementary IDC model [1] containing a calculation of the fluid's permittivity following the Maxwell-Wagner continuum theory [2] in case of beads and the Pauly-Schwan model [3] for cells. Although the topology of the sensor stack results in a non-uniform distribution of the beads or cells on the surface a correlation between the calculated number of particle layer and the saturation value of the sensor's response was found.

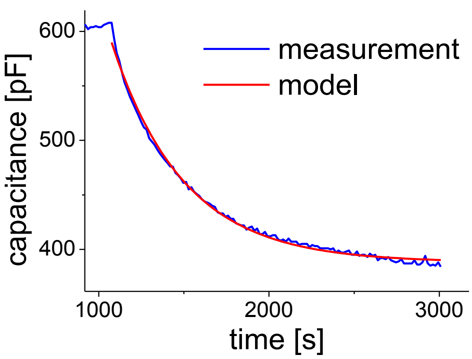

Fig 5: Agglomeration curve (beads, Maxwell-Wagner model)

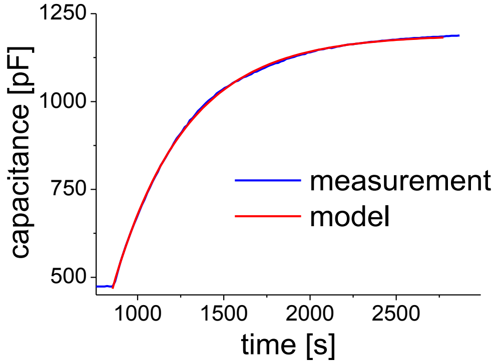

Fig 6: Agglomeration curve (yeast, Pauly-Schwan model)

5. Conclusion and outlook

For the first time a smart (ultra micro) sensor filter was built, which allows the online monitoring of the filter's loading and the possibility for further electroanalysis of the filtrate. A first principles based model of the sensor's response was established. Future work aims on the characterization of the sensor filter under various process conditions and for different filtrate media to qualify the sensor filter for future application fields. In addition the electrodes will be processed directly on the filter membrane which enables an integration of cost effective sensor filters into disposable cartridges.

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